Fermi National Accelerator Laboratory

FERMILAB-Conf-93/210-E
CDF

Measurement of the Ratio

$$R = \frac{\sigma \cdot B(p\bar{p} \rightarrow W^{\pm} \rightarrow e^{\pm}\nu)}{\sigma \cdot B(p\bar{p} \rightarrow Z^{0} \rightarrow e^{+}e^{-})}$$

in $p\bar{p}$ Collisions at CDF

The CDF Collaboration

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in $p\bar{p}$ Collisions at $\sqrt{s} = 1800\ GeV$

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Abstract:

We present preliminary results on the measurement of the ratio of W and Z cross sections in $p\bar{p}$ collisions at $\sqrt{s} = 1800\ GeV$ in the electron decay channel. The data represent approximately 18.4 pb^{-1} from the 1992-1993 run of the Collider Detector at Fermilab. We find $R = 10.64 \pm 0.36$ (stat.) $\pm$ 0.27 (sys.). From this value we extract a value for the ratio of W and Z total decay widths, $\Gamma(W)/\Gamma(Z)$, and set a model-independent limit on the top quark mass m_{top}.

I. Introduction

This paper presents a preliminary measurement of the ratio of W and Z cross sections in the electron channel by the CDF Collaboration using approximately 18.4 pb^{-1} of data accumulated in its 1992-1993 run at the Fermilab Tevatron. The cross section times branching ratio for the W and the Z are sensitive to many aspects of the physics of proton-antiproton collisions, and to many parameters of the Standard Model. In particular, the ratio of cross sections is the most sensitive method to measure the decay width $\Gamma(W)$ of the W boson.[1] The ratio of the cross sections times branching ratios is related to the decay widths via the formula

$$R = \frac{\sigma\left(p\bar{p} \to W \to e\nu\right)}{\sigma\left(p\bar{p} \to Z \to ee\right)} = \frac{\sigma\left(p\bar{p} \to W\right)}{\sigma\left(p\bar{p} \to Z\right)} \frac{\Gamma\left(W \to e\nu\right)}{\Gamma\left(Z \to ee\right)} \frac{\Gamma\left(Z\right)}{\Gamma\left(W\right)} \quad [1]$$

Many systematic and theoretical uncertainties cancel in the ratio. The ratio of the full widths, $\Gamma(W)/\Gamma(Z)$, can be extracted since the total production cross sections and partial decay widths into electrons are predicted from proton structure functions, standard model couplings, and the boson masses. Using precise measurements of the Z decay width, $\Gamma(Z)$, from LEP,[2] the W width can be extracted. The W width is sensitive to unknown decay channels of the W boson. In particular, if the mass of the top quark, m_{top}, is less than $M_W - m_b$, then the partial width $\Gamma(W \to tb)$ will be non-zero. An absence of this partial width sets a limit on m_{top} independent of models of its allowed decay modes. Previous measurements[3] of R have determined the W width to a combined accuracy of 5.2%.

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II. Event Selection

The CDF Detector is described elsewhere.[4] Candidate events for W's and Z°'s were selected from a common sample of events with a well-identified, isolated, high transverse-momentum (P_T) electron in the central region of the detector, where magnetic analysis of the electron's track is possible. Loose identification cuts were then adequate to identify the second lepton in the event (e or ν) with high efficiency. By choosing the W and Z candidates in this way, systematic uncertainties in the integrated luminosities of the W and Z samples and in the identification efficiency of the first electron cancel in the measurement of the ratio.

Events were required to pass a hardware trigger that required (i) a coincidence of counts in trigger counters located forward and backward of the detector, (ii) an energy deposition in the calorimeters within[5] $|\eta| < 1.0$ with $E_T > 18\ GeV$, (iii) a track in the tracking chamber identified by a hardware processor with $P_T > 9\ GeV/c$, and (iv) that the energy deposited in the hadronic compartments in the electron cluster be less than 12.5% of the energy in the electromagnetic compartments. A further software trigger required (v) that the electron had a shower development consistent with electrons from test-beam data and (vi) that the extrapolated position of the electron's track agreed with the electron shower position as recorded by a proportional chamber ('strip' chamber) embedded in the calorimeter at shower-maximum.

Electron candidates were chosen from these triggers if they had (i) clusters in the allowed η region with $E_T > 20\ GeV$, (ii) the ratio of the energy, E, deposited in the calorimeters to the charged track momentum, p, in the range $0.5 < E/p < 2.0$, (iii) the strip chamber profile and the electron shower profile consistent with testbeam electrons, (iv) good matching between the strip chamber position and the charged track's extrapolation, (v) at most 10% of electromagnetic energy of the cluster present in the hadronic compartments, (vi) an event vertex no more than 60 cm (2σ) from the nominal interaction point, and (vii) transverse energy in the towers surrounding the electron cluster in η-ϕ space of no more than 10% of the electron's energy. This last criteria is called our 'Isolation' variable and is computed by calculating the electron cluster's E_T, the total, E_T^{Cone}, of the towers around the electron cluster, $E_T^{Cone} = \sum_i E_T^i$, where E_T^i is the transverse energy of a tower within $\Delta R = 0.4$ ($\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ is the distance from the electron cluster to the nearby tower). We then define the Isolation, Iso, as

$$Iso = \frac{E_T^{Cone} - E_T^{Cluster}}{E_T^{Cluster}}$$

Over 30000 electron candidates passing these criteria were collected. Figure 1 shows the observed spectrum of E_T of these electrons.

Z° candidates were selected by requiring a second electromagnetic calorimeter cluster which passed only loose selection criteria. Clusters in the range (i) $|\eta| < 1.0$ with $E_T > 20\ GeV$, (ii) $1.1 < |\eta| < 2.2$ with $E_T > 15\ GeV$, or (iii) $2.4 < |\eta| < 4.2$ with $E_T > 10\ GeV$ were accepted if they had $Iso < 0.1$. Second electron clusters in the range $|\eta| < 1.0$ were required in addition to possess a track with opposite sign to the first electron and with $P_T > 5$ GeV. Second clusters in the range $2.4 < |\eta| < 4.2$ were required to have a transverse energy profile consistent with test beam data. Finally, the invariant mass, M_{ee}, of the first and second electron clusters was required to be between 66 and 116 GeV/c^2. There are 1053 candidates which pass these criteria. Figure 2 shows the invariant mass distribution of all e^+e^- pairs which pass the electron identification cuts.

W candidates were required to possess a missing transverse energy, $\not{E}_T$, greater than 20 GeV. The $\not{E}_T$ is defined as the magnitude of the vector sum of all transverse energies of calorimeter towers in range $|\eta| < 3.6$: each tower's transverse energy vector is given in magnitude by the E_T in the tower and in direction by the direction of the tower with respect to the origin (the interaction point). The W candidates are also required not to pass the Z° selection criteria. The transverse mass, M_T, spectrum of these candidates, where $M_T = \sqrt{E_T \not{E}_T (1 - \cos(\Delta\phi))}$, and $\Delta\phi$ is the azimuthal separation of the electron cluster and the $\not{E}_T$ vector, is shown in Figure 3. There are 10991 candidates which pass these criteria.

III. Backgrounds

The largest backgrounds to the W candidates are labeled crudely as 'QCD' events: these are events in which hadron jets produce a false signal of an electron + $\not{E}_T$. One jet fluctuates to produce an electron-like cluster and another is mismeasured in the detector to produce $\not{E}_T$. The fluctuations which produce a high-p_T isolated electron can be either a $\pi^\circ \rightarrow \gamma\gamma$ decay, where one of the two γ 's converts in the material before the tracking chambers or the fluctuation can be a b quark which decays semileptonically to an electron. This background is estimated by extrapolating the Isolation distribution of low $\not{E}_T$ events into the high $\not{E}_T$ region. The conversion contamination is independently determined by explicitly searching for an opposite-sign second charged track in the tracking chamber near the electron track for which the track pair forms a low invariant mass. The b-quark contamination is independently determined by using the Silicon Vertex Detector to search for electron tracks consistent with having come from a displaced vertex. The total QCD background is estimated to be 552 ± 46 events.

The process $W \rightarrow \tau\nu$, followed by $\tau \rightarrow e\nu\nu$, can also fake the W signal, as do the processes $Z^\circ \rightarrow ee$, where one of the electrons is not detected, or $Z^\circ \rightarrow \tau\tau$, where one τ decays to an electron and the other is not detected. From studies using the ISAJET Monte Carlo[6] program and a detector simulation, we estimate the backgrounds due to these processes to be 373 ± 3 from $W \rightarrow \tau\nu$, 226 ± 34 from $Z^\circ \rightarrow ee$, and 20 ± 3 from $Z^\circ \rightarrow \tau\tau$. W background from a heavy top is also considered: we take the background to be 0, but with an error given by the expected number of events from a 100 GeV/c^2 top.

Backgrounds to the Z° candidates come from jet production and $Z^\circ \rightarrow \tau\tau$. From a study of the isolation of the two electrons, the jet background to the $Z^\circ \rightarrow ee$ candidates is estimated to be 51 ± 9 events. The background from the process $Z^\circ \rightarrow \tau\tau$, where both tau's decay to electrons is estimated using ISAJET to be 1 ± 1 event. A correction of 1 ± 1 % is applied to the number of Z°

candidates to account for the fact that some e^+e^- pairs are produced by the Drell-Yan γ continuum.

IV. Lepton Identification and Trigger Efficiencies

R, in terms of the experimentally measured quantities, can be written as

$$R = \frac{N_W}{N_Z}\frac{A_Z}{A_W}\frac{\varepsilon_Z}{\varepsilon_W}$$

where $N_W\,(N_Z)$ is the number of W(Z°) candidates, $A_W\,(A_Z)$ is the kinematic acceptance for W's(Z°'s) given our E_T cuts, and $\varepsilon_W\ (\varepsilon_Z)$ is the W(Z°) identification efficiency given the electron identification criteria.

The kinematic acceptances are determined using a monte carlo which generates zeroth order diagrams of W(Z°) production, $q\bar{q}\rightarrow W(Z^\circ)$ with different input parton distribution functions and decays them into electrons. We use the MRSD0 structure functions,[7] but also examine the effect on our result from using the MRSS0, MRSD-, CTEQ1L, and CTEQ1M[8] parton distribution functions. The effects of higher order diagrams to W(Z°) production are input by boosting the bosons by a P_T^{Boson} distribution obtained from a previous measurement[9] of the W's P_T spectrum. A detector model is used to smear the leptons by the nominal energy resolutions and mimick the $\not{E}_T$ resolution. We find that $A_W = 33.8\%$ and $A_Z = 37.2\%$. Systematic uncertainties from the monte carlo from variations the P_T^{Boson} distribution, the boson masses, the detector model, and the choice of parton distribution functions input to the generator are seen to result in a 1.6% uncertainty in A_W/A_Z.

The efficiencies of the selection criteria described above are obtained from the second electron in $Z^\circ\rightarrow ee$ decays, where the Z° is selected based upon the first electron and event topology, but not using the second electron identification criteria. Each of the detector regions, the central ($|\eta| < 1.0$), the plug ($1.0 < |\eta| < 2.2$), and the forward ($2.4 < |\eta| < 4.2$) have their own electron identification efficiency, c, p, f. The central ID efficiency is broken into two classes: the efficiency to pass the stringent cut on the first leg, c_1, and the efficiency to pass the loose cuts on the second leg, c_2. The efficiency of the trigger for central electrons, ε_T, is determined from W's which were taken by a trigger that selected on $\not{E}_T$. These W's were then studied to see how many also passed the electron trigger. The ratio of the W and Z efficiencies can then be written as

$$\frac{\varepsilon_Z}{\varepsilon_W} = \frac{(\varepsilon_T \cdot c_1)\ [\ F_{cc}(2c_2 - \varepsilon_T c_1) + F_{cp}p + F_{cf}f\ ]}{\varepsilon_T \cdot c_1}$$

where F_{cc}, F_{cp}, and F_{cf} are the fraction of the $Z^\circ\rightarrow ee$ events in which the second electron goes in the central, plug, and forward. These fractions are determined using the monte carlo described above. The efficiency $\varepsilon_T c_1$ cancels almost completely in the ratio because a central electron is required for both W's and Z's.

V. Results and Conclusions

The results from Sections 2 through 4 are summarized in the Table 1 below. Assembling all of the numbers, we find

$$R = 10.64 \pm 0.36\,(\text{stat.}) \pm 0.27\,(\text{sys.}).$$

We use the theoretical calculation[10] of the ratio of production cross sections, $\sigma(p\bar{p}\to W)/\sigma(p\bar{p}\to Z) = 3.23 \pm 0.03$, and the calculation of the ratio of partial widths, $\Gamma(W\to e\nu)/\Gamma(Z\to ee) = 2.696 \pm 0.018$ in order to extract the ratio of the decay widths, $\Gamma(W)/\Gamma(Z)$ from Equation [1]. We extract $\Gamma(W)/\Gamma(Z) = 0.818 \pm 0.028$ (stat) ± 0.023 (sys). Together with the LEP value[11] for the Z width $\Gamma(Z) = 2.487 \pm 0.009$ we may extract a value for the W width:

$$\Gamma(W) = 2.033 \pm 0.069\,(\text{stat.}) \pm 0.057\,(\text{sys.})\ GeV.$$

This is a 4.4% measurement of the W width. For comparison, the Standard Model value[12] is 2.083 ± 0.016 GeV.

Recent papers[13] have speculated as to whether 'new physics' would alter the W boson's coupling, g, to fermions. The W width is proportional to $g^2 M_W$, where the constant of proportionality $(9.228/48\pi)$ may be determined using electroweak Feynman rules and QCD. Using our value for the W width and the world average value for the W mass,[12] we find that the W coupling, g, to fermions at $q^2 = M_W^2$ is $g = 0.644 \pm 0.014$. From the value of G_F from muon decay and the world average for M_W, one expects that $g = 0.651 \pm 0.002$ at $q^2 \equiv 0$. Our result thus shows no visible running of the coupling with q^2 and no visible deviation from the Standard Model coupling due to 'new physics.'

If we instead use the LEP value[14] for the partial width $\Gamma(Z\to ee) = 83.0 \pm 0.5$ MeV, we can obtain a precise value for the branching ratio

$$\Gamma(W\to e\nu)/\Gamma(W) = 0.1100 \pm 0.0036(\text{stat.}) \pm 0.0031(\text{sys.}).$$

Recent searches have set lower limits on the top quark mass at 108 GeV/c^2 using Standard Model decays.[15] As shown in Figure 4, this value of the branching ratio excludes m_{top} below 62 GeV/c^2 at the 95% confidence level, independent of the allowed decay modes of the top.[16]

Table 1: Summary of Results for R

	W's	Z's
Candidates	10991	1053
Background		
QCD	552 ± 46	51 ± 9
$W \to \tau\nu$	373 ± 3	-
$Z \to \tau\tau$	20 ± 3	1 ± 1
$Z \to ee$	226 ± 34	-
heavy top	0^{+62}_{-0}	-
Total Background:	1175^{+91}_{-59}	52 ± 9
Signal	$9816 \pm 105 \pm 77$	$1001 \pm 32 \pm 9$
Acceptance		
A_W, A_Z	0.338 ± 0.006	0.372 ± 0.006
A_W/A_Z	0.908 ± 0.015	
F_{cc}	-	0.397 ± 0.001
F_{cp}	-	0.466 ± 0.001
F_{cf}	-	0.138 ± 0.001
Efficiencies		
$\varepsilon_T c_1$	0.749 ± 0.013	0.749 ± 0.013
c_2	-	0.961 ± 0.007
p	-	0.880 ± 0.014
f	-	0.723 ± 0.180
$\varepsilon_W, \varepsilon_Z$	0.749 ± 0.013	0.731 ± 0.015
$\varepsilon_W/\varepsilon_Z$	1.025 ± 0.012	
Drell-Yan Correction	-	1.01 ± 0.01
$\sigma(W \to e\nu)/\sigma(Z \to ee)$	10.64 ± 0.36 (stat.) ± 0.27 (sys.)	

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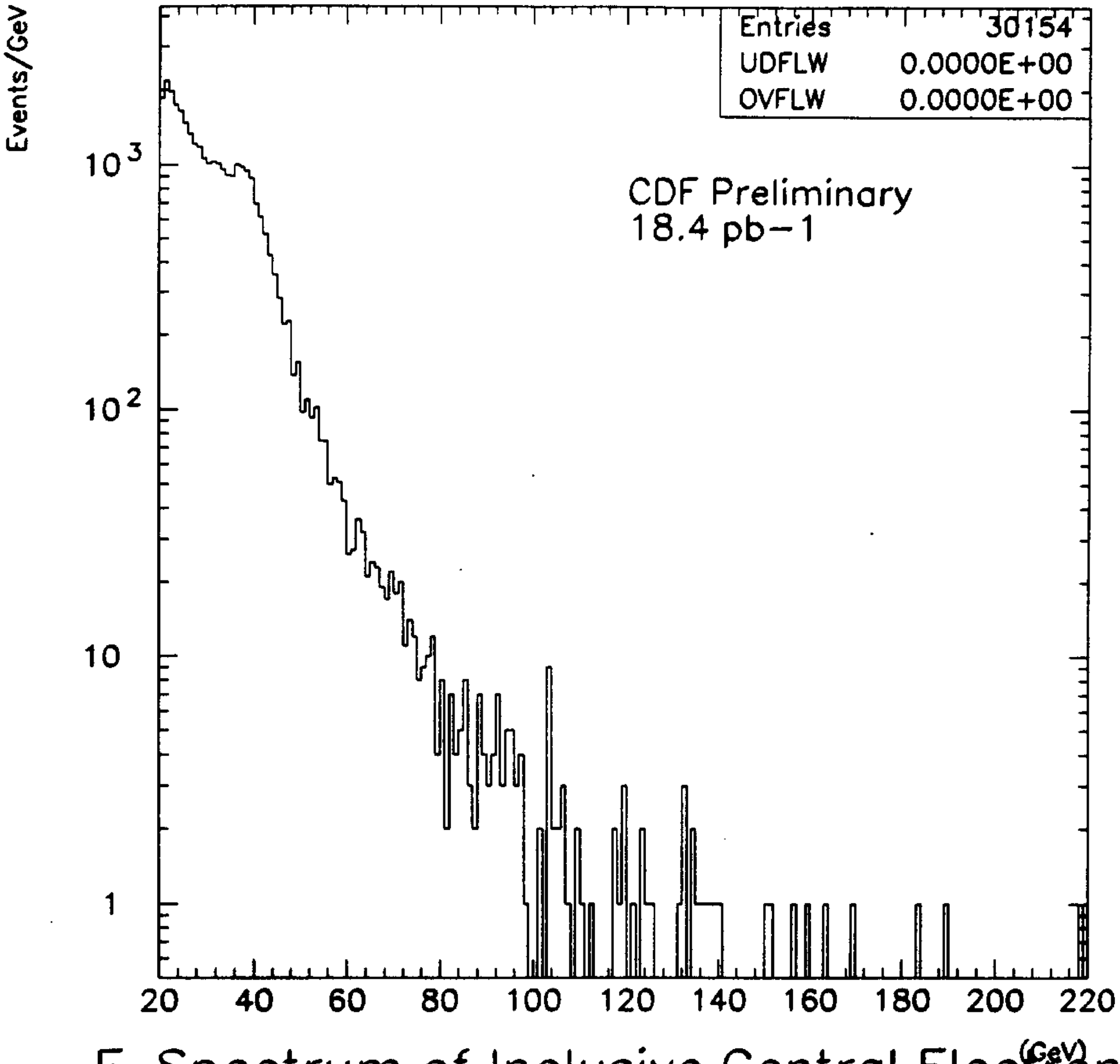
Figure 1: The tranverse energy, $E_T = E\sin\theta$, of the inclusive electron sample



E_T Spectrum of Inclusive Central Electrons

Figure 2: The Invariant Mass spectrum of e^+e^- pairs observed.

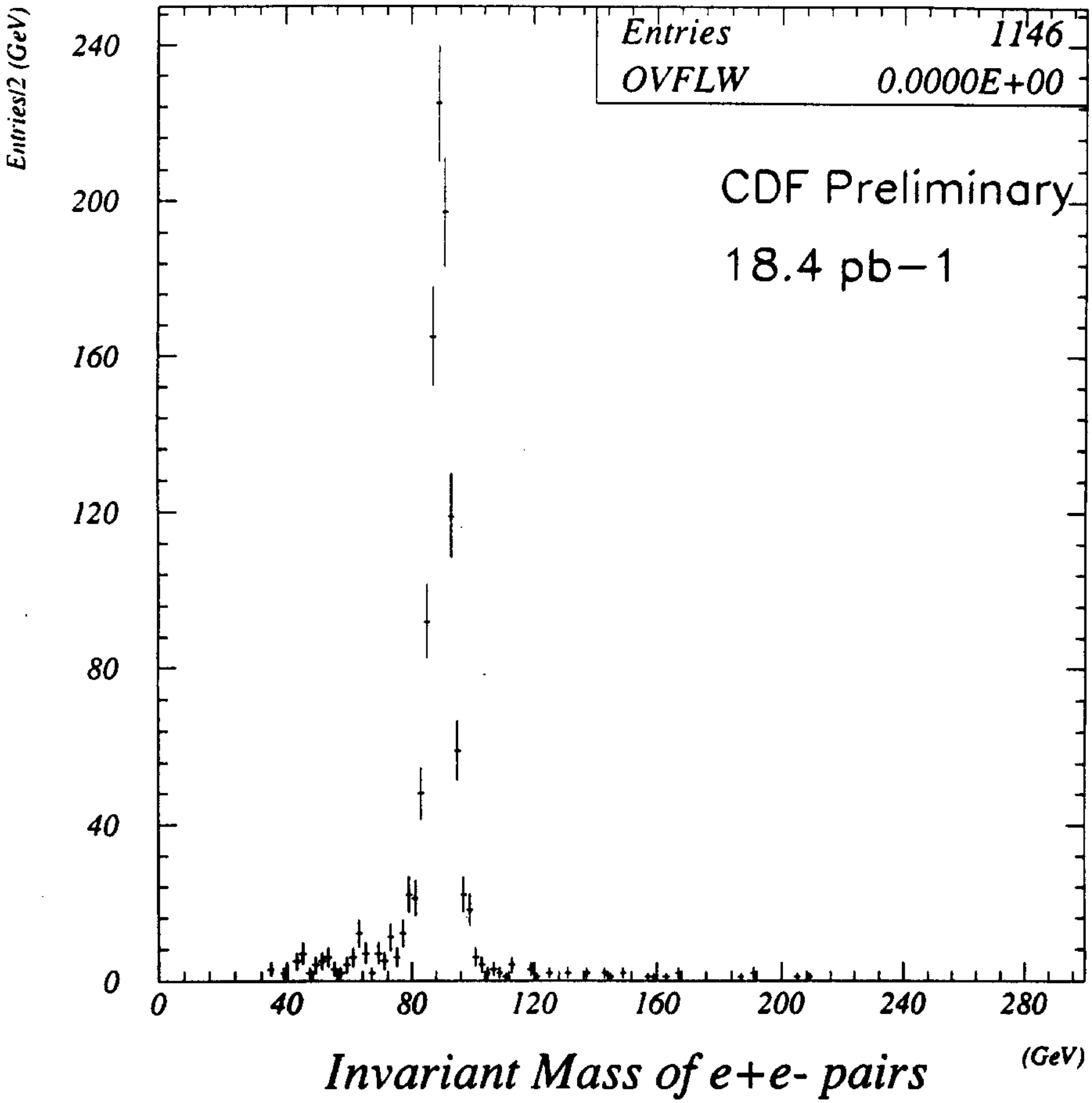


Figure 3: The Transverse Mass, M_T, spectrum of W candidates.

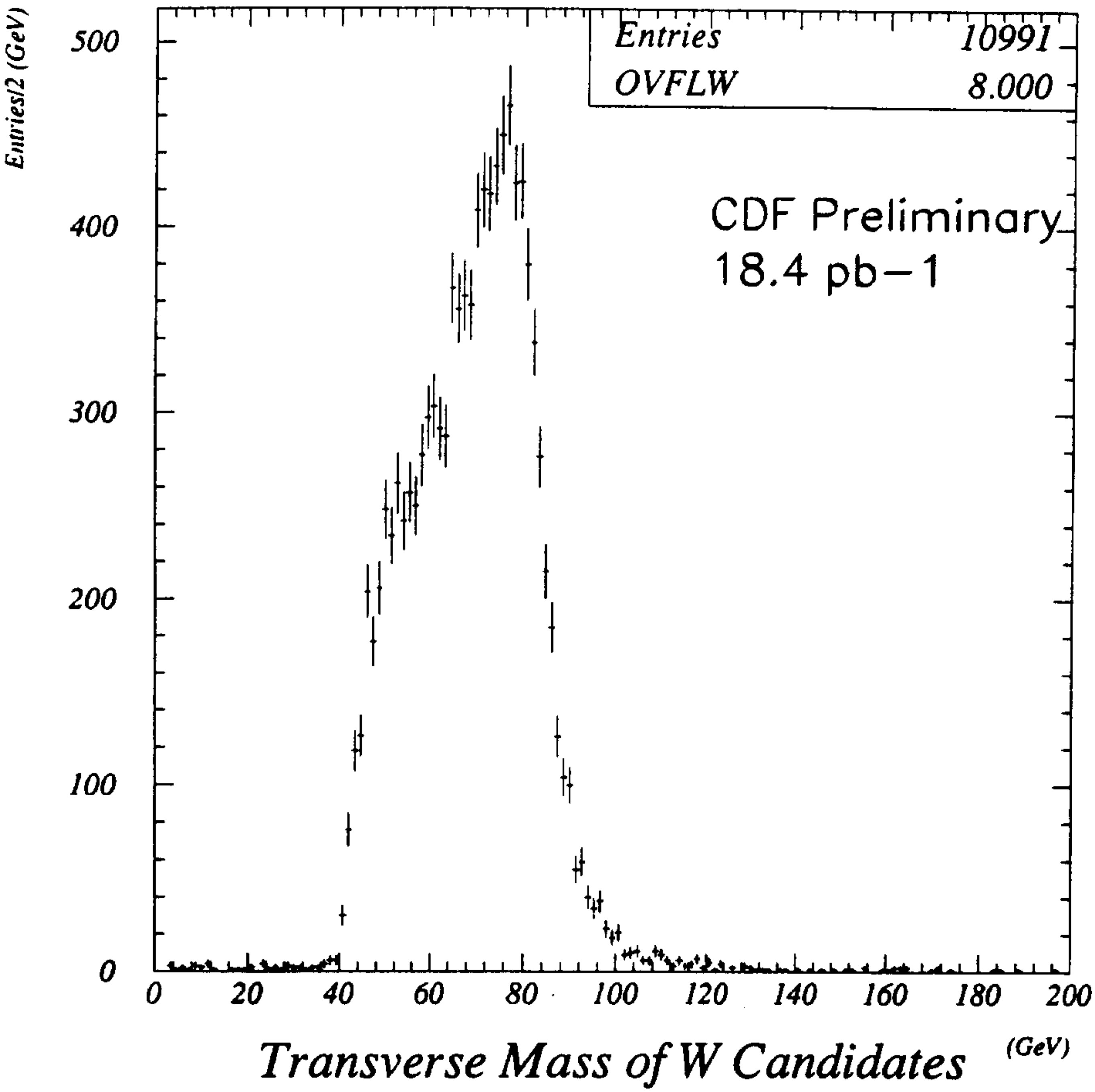


Figure 4: The 'Inverse Branching Ratio,' $[\Gamma(W\to e\nu)/\Gamma(W)]^{-1}$, as a function of the top mass, m_{top}.